

## Research

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Limited Environmental Impact  
on Stratosphere:Research on Rocket Launch Exhausts  
Supports Continued Access to Space

**N**ew AFOSR-sponsored research shows that exhausts from solid-fueled rocket motors have very limited impact on stratospheric ozone. The research provides the Air Force with hard data to support continued access to space using the existing fleet of rockets and rocket technology. This basic research data allows the Air Force:

- to maintain a strongly proactive environmental stance, and
- to meet federal guidelines regarding environmental impacts.

Long-standing conjecture within the international rocket community suggests that chlorine compounds and alumina particulates produced in solid rocket motor (SRM) exhausts could create localized, temporary ozone loss in rocket plumes following launches. The extent of a local depletion of ozone and its environmental impact depends on details of the composition and chemistry in these plumes. Yet direct measurements of plume composition and plume chemistry in the stratosphere had never been made. Uncertainty about these details left the Air Force and commercial space launch capability potentially vulnerable to questions about the environmental impact of rocket launches.

In 1995, AFOSR and the Space and Missiles Systems Center Launch Programs

Office (SMC/CL) jointly began the Rocket Impacts on Stratospheric Ozone (RISO) program to make the first-ever detailed measurements of rocket exhaust plumes. These measurements were aimed at understanding how the exhaust from large rocket motors effect the Earth's stratospheric ozone layer. The studies determined:

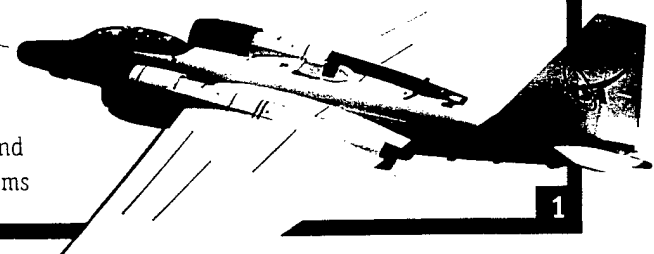
- the size distribution of alumina particles in these exhausts,
- the amount of reactive chlorine in SRM exhaust, and
- the size and duration of localized ozone loss in the rocket plumes.

AFOSR-supported researchers from the University of Missouri-Rolla and the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VSBP) at Hanscom AFB designed and created ultra-sensitive instruments to measure and analyze the composition of these exhaust plumes in the stratosphere just after launch.

The instruments were carried into the ozone layer aboard a NASA WB-57F aircraft. The plane flew "figure-eight"

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## Rocket Launch Exhausts

continued from front cover...



Dr. Martin Ross

patterns in and out of the rocket plume wakes for up to two hours after launch, in some cases penetrating the plume up to 18 times. Dr. Martin Ross, the RISO program manager for the Aerospace Corporation's Environmental Systems Directorate, led the RISO team.

From April 1996 to August 1997, the RISO WB-57F team flew six sampling missions through the plumes of three Titan IV, two Space Shuttle, and one Delta II rocket boosters. During this 16-month period, the AFOSR-SMC team made several important discoveries:

- They determined that the actual mass of alumina particulates from SRM exhaust plumes that stays suspended in the stratosphere is 200 times less than the assumed mass used in recent models. This data dispels prior "worst-case scenario" speculation concerning the environmental impact of SRM exhausts.
- They measured, for the first time, molecular-chlorine in the stratosphere. This measurement confirmed the theory of molecular-chlorine production in SRM plumes caused by afterburning reactions.
- They verified models of SRM's hot plume chemistry. Researchers can now determine ozone loss in plumes. They found that local ozone loss in plume wakes begins several minutes after launch, reaches its maximum after about 45 minutes, then abates.

The plume-fly-through experiments are complemented by AFOSR-funded laboratory studies that explore the detailed chemical reactions that occur in the plume environment. AFOSR is funding Prof. Mario Molina of the Massachusetts Institute of Technology, to investigate the role that reactions on alumina surfaces can have in ozone depletion. Prof. Molina has determined that reactions on alumina particulates produced in SRM exhausts do not greatly enhance ozone depletion in the atmosphere. (Prof. Mario Molina won the 1998 Nobel Prize in Chemistry for his discovery of the impact that chlorofluorocarbons have on atmospheric ozone.)

These stratospheric measurements and laboratory experiments provide an important step forward for the AFOSR-SMC team's goal of assessing the impact that rockets have on the stratosphere. The research results provide, for the first time, hard data on the impact of SRM exhausts on stratospheric ozone depletion.

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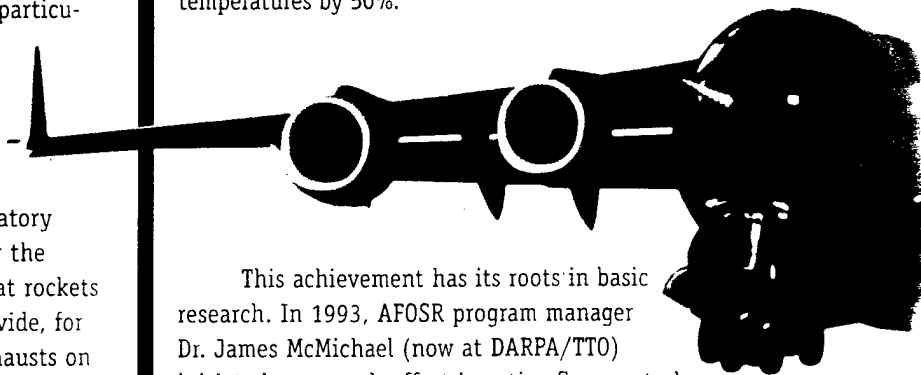
# Active Flow Control Tech Jet Engine Life Cycle Cos

**AFOSR**-funded research has led to the successful demonstration of active flow control technology to reduce jet engine exhaust temperatures on a full-scale JT8D-15 jet engine. Boeing C-17 aircraft engineers believe that this temperature reduction could significantly reduce powered airlift costs. Active flow control allows:

- titanium plates used to protect the underside of C-17 flaps to be fabricated from less expensive and lighter high-temperature aluminum, saving weight and reducing manufacturing and maintenance costs;
- exhaust cooling to be applied selectively, for instance, only on take off and landing; and
- expensive and heavy core thrust reversers, which deflect hot plumes away from the loadmasters on the ground, to be replaced with active flow control systems.

These factors could reduce life-cycle cost by up to \$1.5 million per aircraft.

In 1995, Dr. Steven Walker of the Wright Laboratory Flight Dynamics Directorate (now AFRL/VAA), initiated the FLINT (Fluidic Injection Nozzle Technology) program to develop fluidic actuator concepts for jet mixing, nozzle area control, and nozzle thrust vectoring. The idea was to use fluidic rather than mechanical means to control a jet, thus reducing the number of mechanical parts. Implementing the fluidic concept reduces system weight and cost. Under the FLINT program, a Boeing/Allied Signal/Pratt & Whitney contractor team led by Mr. John Dorris, demonstrated the pulsed-jet, active, core exhaust (ACE) control system on a full-scale, JT8D-15 engine using off-the-shelf hardware. The ACE system reduced exhaust plume temperatures by 50%.



This achievement has its roots in basic research. In 1993, AFOSR program manager Dr. James McMichael (now at DARPA/TTO) initiated a research effort in active flow control at Georgia Tech. In 1994, Boeing and the University of Arizona initiated experimental, theoretical, and computational research in jet mixing, shear layer receptivity, and active flow control, which provided insight into the dynamics of the jet shear layer. They accomplished this by identifying the inherent instability

# Low Control Technology to Cut Millions From Life Cycle Costs

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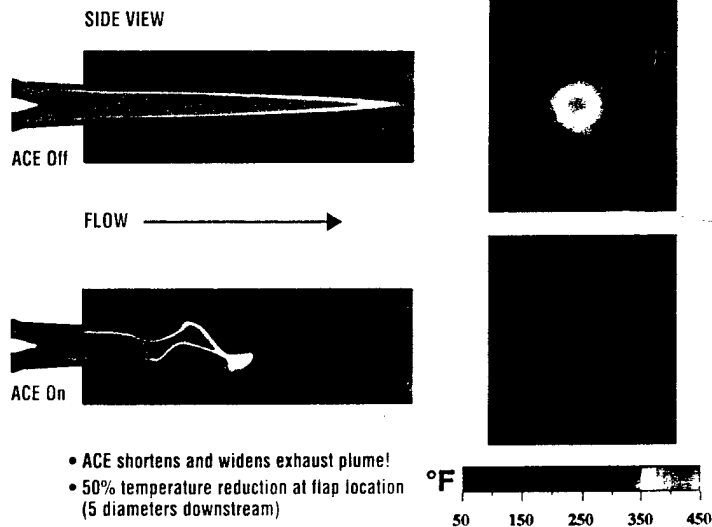
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BELOW: Active Core Exhaust (ACE) control  
technology can reduce jet engine temperatures  
at the C-17 flap location by up to 50%.



RIGHT: Under the FLINT  
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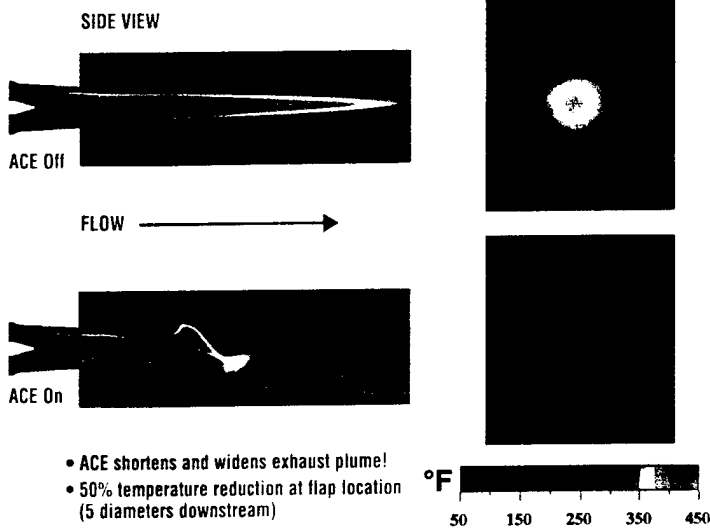
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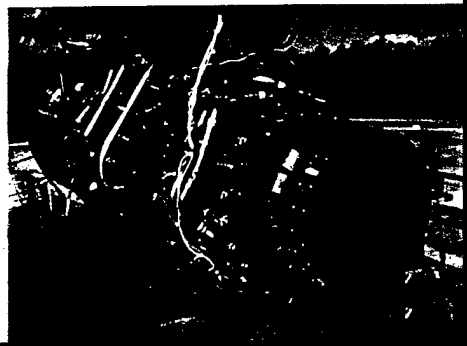
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Directorate for Aerospace and Materials Sciences

# ogy to Cut Millions From

BELOW: Active Core Exhaust (ACE) control technology can reduce jet engine temperatures at the C-17 flap location by up to 50%.



RIGHT: Under the FLINT program, a contractor team led by Mr. John Dorris, demonstrated Active Core Exhaust (ACE) control on a full-scale, JT8D-15 using off-the-shelf hardware.



BELOW: By reducing jet engine exhaust gas temperatures, expensive structural components could be fabricated from less costly materials.

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## Multiplexed Diode Laser Array

### New Sensing Capability to Benefit Feedback Control for Propulsion Systems

Under AFOSR basic research support, Prof. Ron Hanson at Stanford University has developed a multiplexed diode laser array that provides sensing capability for closed-loop feedback control of a shipboard incinerator. This type of closed-loop system could allow on-board control of Air Force propulsion systems. Such control could mitigate combustion instabilities, reduce fuel consumption, minimize infrared signatures, and stabilize combustion performance in extreme operation conditions.

As part of the Department of Defense's (DoD) Strategic Environmental Research and Development Program (SERDP), the Navy received SERDP support to develop a compact, lightweight shipboard waste incinerator to process waste to comply with international treaties which banned the dumping of shipboard waste at sea.

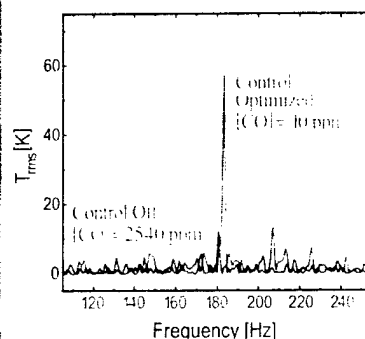
To meet clean air restrictions while maintaining compactness and robustness, Naval Air Warfare Center Weapons Division (China Lake, Calif.) researchers developed a pulsed-air injection concept that created vortex rings inside the incinerator. Precise timing and location of waste and fuel injection into these vortices achieved very good mixing with incoming air. A closed-loop, active control system — which relied on Professor Hanson's

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Right:



BELOW RIGHT:



# Technology Transition Spotlight

In each issue, *Research Highlights* will feature a recent technology transition that benefits Air Force operations.

**Customer ....** The Air Force Corrosion Program Office at Robins AFB, Ga. (AFRL/MLS-OLR) adopted a magnetic field detection device (SQUID – see “basic research” section below) in 1997 as a method to determine the corrosion rate of aircraft materials and structures (lap joints, seams, extruded parts) exposed to the atmosphere or other non-aqueous environments.

**Benefit .....** Many off-the-shelf corrosion tools exist to measure corrosion rates by passing electric currents through exposed corroding sample surfaces, usually submerged in salt water. The SQUID magnetometer system allows researchers to observe real, instantaneous corrosion currents, hidden deep within a lap joint, caused by the aircraft’s environmental factors (such as humidity, salt deposition) and to determine actual levels of corrosion activity. Using this technique, researchers can now develop corrosion growth models — previously an impossible task.

**Basic Research ....** Researchers used a Superconducting Quantum Interference Device (SQUID) magnetometer system and support apparatus to observe and record the signals from corrosion occurring at the rate of one mil (40 micrometers) per year, or less. The rates were detected during a one to two-hour period in a simulation of the aircraft’s actual environment to observe real-time results. Use of the SQUID eliminates the need to artificially accelerate corrosion rates.

**Performer ...** Dr. John Wikswo, a Vanderbilt University professor, led a research team, including NCI Information Systems and Dr. Rob Kelly of the University of Virginia, in performance tests to prove the technique. Structural aircraft samples were provided by NCI and the Air Force Corrosion Program Office (AFCP0). Mr. Richard Kinzie, a materials engineer in the AFCP0 (912-926-3284), supervised the research.

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*Research Highlights* is published every two months by the Air Force Office of Scientific Research. The newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available online at:

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laser diode absorption sensor — modulated combustion. This incinerator configuration reduced emissions to levels that meet Clean Air Act regulations.

Hanson’s sensor consists of two diode lasers transmitting narrow, collimated (parallel) beams at wavelengths of 1392 nanometers (nm) and 1343 nm through the combustor. The detected reduction in the laser’s intensities provide

quantitative information about the temperature and concentration of water vapor in the combustor. These parameters were sampled at 10 kHz (10,000 samplings per second), which allows dynamic control of the incinerator operation. The optical quality, robustness, and affordability of diode laser technology make it an extremely practical approach.

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